Contemporary management of patients with multiple rib fractures: What you need to know

Babak Sarani, MD, FACS, FCCM *and* **Fredric Pieracci, MD, FACS**, *Washington, District of Columbia*

ABSTRACT: Ten percent of all injured patients and 55% of patients with blunt chest trauma experience rib fractures. The incidence of death due to rib fractures is related to the number of fractured ribs, severity of fractured ribs, and patient age and comorbid conditions. Death due to rib fracture is mostly caused by pneumonia because of inability to expectorate and take deep breaths. Over the last 25 to 30 years, there has been renewed interest in surgical stabilization of rib fractures (SSRF), known colloquially as "rib plating." This review will present what you need to know in regard to triage decisions on whether to admit a patient to the hospital, the location to which they should be admitted, criteria and evidentiary support for SSRF, timing to SSRF, and operative technique. The review also addresses the cost-effectiveness of this operation and stresses nonoperative treatment modalities that should be implemented prior to operation. (*J Trauma Acute Care Surg.* 2024;97: 337–342. Copyright © 2024 Wolters Kluwer Health, Inc. All rights reserved.)

KEY WORDS: Rib fracture; rib plating; surgical stabilization of rib fractures.

Rib fracture is the most common form of chest wall injury and also one of the most common forms of overall injury. It is estimated that 10% of all injured patients and 55% of patients with blunt chest wall injuries have rib fractures.[1] Although the incidence of death due solely to rib fractures has decreased in the last 25 years, the most recent large study on this topic found a 3% incidence in all patients with rib fractures.[2] However, this incidence increased to approximately 9% in patients with eight or more rib fractures and increased further to 35% in patients 65 years and older. The relationship between mortality and the number of broken ribs as well as the aggravating impact of increasing age is a constant finding in many studies, with one study finding a 19% increase in the odds ratio of death with each fractured rib.[3–5]

The most common cause of death in patients with rib fractures is pneumonia due to pain associated with coughing, deep breathing, and movement. Less commonly, patients with severe chest wall disruption, as may be seen in patients with flail chest injury, can result in loss of the bellows function of the chest wall and thus inability to move sufficient tidal volume. This, in turn, will result in progressive hypercapneic and, ultimately, hypoxic respiratory failure.

Traditionally, even the most severe rib fracture patterns were treated exclusively with pain medications, which were mostly centered on opioids. Although analgesia remains the mainstay of therapy for most patients with rib fractures, a more sophisticated approach is now used, centered around multimodal medications, including nonopioid infusions, locoregional nerve blocks, and, in certain cases, intercostal nerve cryoablation, although the latter modality has not been shown to be consistently effective. Attempts to use prolonged mechanical ventilation as a means to pneumatically stabilize flail chest fracture segments were found to increase mortality, likely because of ventilator-associated pneumonia.[6] Because of the persistent mortality rate associated with nonoperative management of rib fractures, a renewed interest in surgical stabilization of rib fractures (SSRF; also known as "rib plating") developed in earnest in the late 1990s and early 2000s. Proponents of SSRF argue that the operation allows for anatomically correct reduction and fixation of the fracture segments to allow healing, a core principle of orthopedic surgery. This, in turn, is presumed to lessen pain and therefore allow for appropriate pulmonary hygiene and chest wall mechanics during inspiration. As pain control improves, the need for opioid medications is expected to lessen, which improves respiratory drive and cough, thereby decreasing the incidence of pneumonia, need for ongoing mechanical ventilation, and, ultimately, death. Surgical management of rib fractures also provides an opportunity to address additional thoracic pathologies, such as secretion clearance via bronchoscopy, and pleural space clearance via video-assisted thoracoscopic surgery, while the patient is under general anesthesia.

The last two decades have seen an exponential increase in SSRF-related publications. Unfortunately, such publications must be interpreted with caution because of variable definitions of flail chest, indications for surgery, surgical experience and technique, and time from injury to fixation. Moving forward, a standard paradigm for reporting SSRF trials has been proposed.[7] Despite the aforementioned theoretical mechanisms of benefit of SSRF, clinical studies have not found universal benefit, and patient selection remains key in optimizing outcomes of this operation. This review will focus on triage criteria for patient admission, criteria for SSRF, outcomes of SSRF based on various fracture patterns and special patient populations, and the cost-effectiveness of this operation. Given the paucity of studies on SSRF in patients with nonunion or chronic fractures, this review

Submitted: March 14, 2024, Revised: March 18, 2024, Accepted: March 18, 2024, Published online: March 29, 2024.

From the Center for Trauma and Critical Care, Department of Surgery (B.S.), George Washington University, Washington, DC; and Department of Surgery (F.P.), Denver Health Medical Center, Denver, Colorado.

Address for correspondence: Babak Sarani, MD, FACS, FCCM, Surgery and Emergency Medicine, Center for Trauma and Critical Care, Department of Surgery, George Washington University, 2150 Pennsylvania Ave, NW #6B, Washington, DC 20037; email: bsarani@mfa.gwu.edu.

DOI: 10.1097/TA.0000000000004338

Copyright © 2024 Wolters Kluwer Health, Inc. All rights reserved.

SHOUT
SHARE
IT

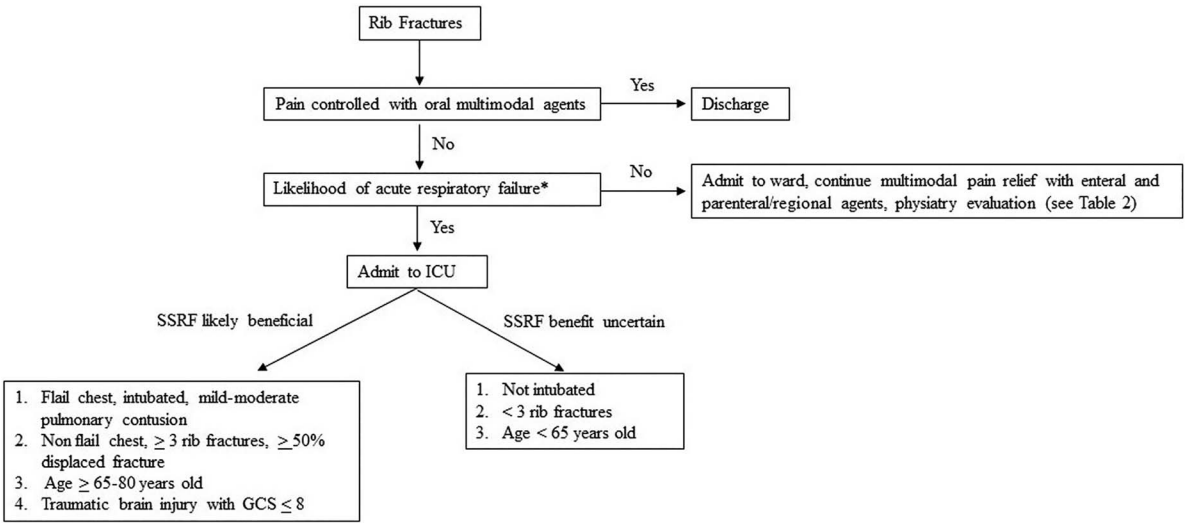
Rib Fractures
Pain controlled with oral multimodal agents
Yes
Discharge
No
Likelihood of acute respiratory failure*
No
Admit to ward, continue multimodal pain relief with enteral and parenteral/regional agents, physiatry evaluation (see Table 2)
Yes
Admit to ICU
SSRF likely beneficial
SSRF benefit uncertain
1. Flail chest, intubated, mild-moderate pulmonary contusion
2. Non flail chest, ≥ 3 rib fractures, ≥ 50% displaced fracture
3. Age ≥ 65-80 years old
4. Traumatic brain injury with GCS ≤ 8
1. Not intubated
2. < 3 rib fractures
3. Age < 65 years old

Figure 1. Overview of management of patients with rib fractures.

is restricted to management of acute fractures only. The authors' conflict of interest forms are available as Supplemental Digital Content.

PATIENT TRIAGE REGARDING ADMISSION TO THE HOSPITAL

The cornerstone of treatment of all but the most severely injured patients with rib fractures is pain control. Thus, the decision as to whether a patient warrants admission to the hospital starts with determining if pain during breathing and coughing can be controlled with oral medications. If this is not possible to the point where the patient can carry out his/her activities of daily living, the patient should be admitted to the hospital. The next decision point is to determine admission to the general medical/surgical ward versus the intensive care unit (ICU). This decision point must factor the propensity for respiratory failure due to inadequate chest wall excursion and tidal volume. Frequently, testing with a bedside spirometer as a means to measure tidal volume can be helpful, although there are no prospective studies determining a cutoff value below which ICU admission is advised.

There are several retrospective scoring systems that predict respiratory failure due to rib fractures.[8,9] These scores are useful for deciding which patients warrant admission to the hospital and which patients may benefit from admission to the ICU. However, there are no studies validating use of these scores as a means to select patients for SSRF. Recently, a single-center study created an algorithm that addresses the decision to admit a patient to the hospital, decision regarding admission to the general ward versus the ICU, and also criteria for discharge from the hospital.[10] Although the algorithm has not been prospectively validated, it is the most comprehensive guide to date.

PATIENT SELECTION FOR SSRF

Patient selection for SSRF as compared with nonoperative management rests mainly on the ability to provide adequate pain relief using a multimodality approach[11] (Fig. 1, Table 1). Such treatment starts with around-the-clock administration of acetaminophen and nonsteroidal anti-inflammatory agents, if possible. Despite its ongoing use, gabapentin has not been shown to be beneficial in this patient population.[12] Both continuous ketamine and intravenous lidocaine infusions have been shown to decrease overall opioid need, although the effect of lidocaine appears to be more short-lived.[13–15] At the authors' institution, both agents are routinely infused on the medical/surgical ward. Telemetry monitoring is required only in patients on a lidocaine infusion. When possible, regional and neuroaxial blocks offer the benefit of robust pain control,[5,16–18] sometimes without the need for hospitalization, as the patient can be discharged to home with a disposable pump. Patient's whose pain cannot be optimally controlled despite appropriate multimodal therapy or those with such severe chest wall injury that normal chest wall function is impaired may be candidates for SSRF. Thus, SSRF should be considered primarily as a means to augment pain control in all but the most severe cases of true chest wall deformity and instability when it is needed to reestablish normal chest contour and function.[19]

The strongest evidentiary support of SSRF is in patients with acute respiratory failure due to flail chest. Numerous retrospective and randomized, prospective studies as well as meta-analyses have found that SSRF in this population is associated with shortened ICU and hospital length of stay, decreased need for mechanical ventilation, and possible mortality benefit.[20–27]

TABLE 1. Multimodality Pain Regimen*

Acetaminophen, around the clock
NSAID around the clock (when possible)**
Lidocaine infusion (short term)
Ketamine infusion
Regional block
Neuroaxial block

*Medications are depicted in order of escalating potency.
**The authors prefer a COX-2 inhibitor to minimize adverse effects of nonselective COX inhibitors.
COS-2, cyclo-oxygenase-2; NSAID, nonsteroidal anti-inflammatory drug.

© 2024 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2024 Wolters Kluwer Health, Inc. All rights reserved.

TABLE 2. Evidence-Based Outcomes Based on Indication for Operation

Indication	Outcome
Flail chest, on ventilator, minimal to moderate pulmonary contusion	Faster extubation, shorter ICU and hospital lengths of stay, lesser need for tracheostomy
Flail chest, not on ventilator	Inconsistent data on hospital stay and pain
≥3 Rib fractures, at least 50% displaced, nonflail chest, moderate pulmonary dysfunction*	Improved respiratory quality of life for 2 wk, improved pain score for 2 mo
Age >80 y old with moderate to severe rib fractures	60% Decrease in mortality
Traumatic brain injury and severe chest wall injury	60–80% Decrease in mortality, shorter ICU, and hospital lengths of stay
Inability to wean from ventilator because of pain associated with rib fractures or inherent chest wall instability	Faster extubation, shorter ICU and hospital lengths of stay, lesser need for tracheostomy

This benefit appears to be greatest in patients whose respiratory failure is primarily due to the chest wall injury as compared with underlying parenchymal injury, such as severe pulmonary contusion.[28,29] The latter group benefits less from SSRF because the need for ongoing mechanical ventilation and its inherent morbidity persists after chest wall stabilization. Table 2 summarizes the indications and associated outcomes of SSRF based on injury pattern and patient demographic.

It is important to note that, despite the attention given to SSRF in flail chest patients, less than 1% of patients admitted with rib fractures suffer from the paradoxical chest wall motion originally described as a clinical flail chest. When determining the role of SSRF based on rib fracture pattern in patients without a flail chest, a survey study of the members of the Chest Wall Injury Society found that most surgeons were likely to recommend SSRF in patients with three or more rib fractures that are 50% or more displaced and who have a resultant moderate degree of pulmonary dysfunction.[30] A follow-up, prospective, observational study of SSRF in this patient population found short-term improvement in pain score and respiratory quotient quality-of-life measures in patients who underwent SSRF.[31] Another retrospective study of a large patient database found that patients without flail chest injury who underwent SSRF had a higher incidence of discharge to home and lower respiratory morbidity up to 1 year following operation.[20] This is congruent with the overall recommendation to offer SSRF as a means to augment pain relief in patients whose pain cannot be controlled medically (Table 2). To date, the biggest study to suggest otherwise involved 207 patients older than 8 years at 15 sites.[26] The study found that SSRF was only beneficial in patients who were intubated but did not discern between flail and nonflail injury pattern.

A consistent benefit of SSRF across multiple studies has been reduction in the incidence of retained hemothorax, potentially because of pleural space evacuation at the time of surgery.[31,32]

Special Populations

The geriatric population is particularly prone to falling and thus to chest wall injury. As previously noted, there is a direct relationship between age and death in patients with rib fractures.[4] This population is more susceptible to the adverse consequences of opioid medications, is more likely to develop delirium from prolonged hospitalization, and is more likely to be frail on arrival to the hospital. A multicenter study of patients 80 years and older with moderate to severe chest wall injury found a 60% decrease in likelihood of death in the group that underwent SSRF.[33] The difference was particularly striking, as the SSRF group was more severely injured than the nonoperative group.

Because chest wall injury is usually due to blunt force injury, it commonly presents concomitantly with traumatic brain injury. Historically, traumatic brain injury was considered a contraindication for SSRF. However, a recent multicenter study[34] and a Trauma Quality Improvement Project-based study[35] found a 66% to 80% decrease risk of death following SSRF in patients with severe traumatic brain injury. Severe traumatic brain injury was defined as a Glasgow Coma Scale score of 8 or less.

Patients with rib fractures that are within 2 to 3 cm of the transverse process of the vertebrae may not benefit from SSRF. This paravertebral ligaments and muscles often allow for stabilization of the fractures, even if the fracture segments are displaced. As well, the proximity to the transverse process may not allow for a sufficient landing zone for proper fixation of the plate to the rib.

TIMING OF SSRF

A key principle of orthopedic surgery is early stabilization of fracture segments to mitigate ongoing inflammation and hemorrhage. In addition, fibrous tissue will begin to deposit at the fracture site within 3 to 5 days following injury, thereby making reduction of the displaced fracture segments more difficult. As such, earlier (defined as less than 72 hours following injury) SSRF is associated with shorter operative times, less intraoperative blood loss, decreased need for postoperative mechanical ventilation, pneumonia, and length of stay.[36–38] These results remained unchanged in a study that evaluated timing to operation in patients with traumatic brain injury.[39] More recently, the window to perform early SSRF has been pushed to within 24 hours of injury when feasible.[40]

DIAGNOSIS AND LOCALIZATION OF RIB FRACTURES

Plain x-ray lacks sensitivity to reliably diagnose rib fractures. Standard, two-dimensional (2D) computed tomography (CT) scan is the imaging test of choice to diagnose the presence of rib fractures and also to determine the fracture pattern and severity (Figs. 2 and 3).[41] Use of three-dimensional CT image reconstruction has become readily available in most centers in the last 15 years (Fig. 4). A study comparing these two imaging modalities found that 2D imaging was better for diagnosing the presence of fractures, whereas three-dimensional was better for operating planning.[42] The surgeon must be cognizant of how the patient was positioned at the time when the CT scan was obtained as the location of the scapula changes based on the positioning of the patient's arms. This can impact intraoperative exposure of the fracture.

OPERATIVE TECHNIQUE

There are five commercially available rib plating systems in the United States, four of which involve implant of a titanium

© 2024 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2024 Wolters Kluwer Health, Inc. All rights reserved.

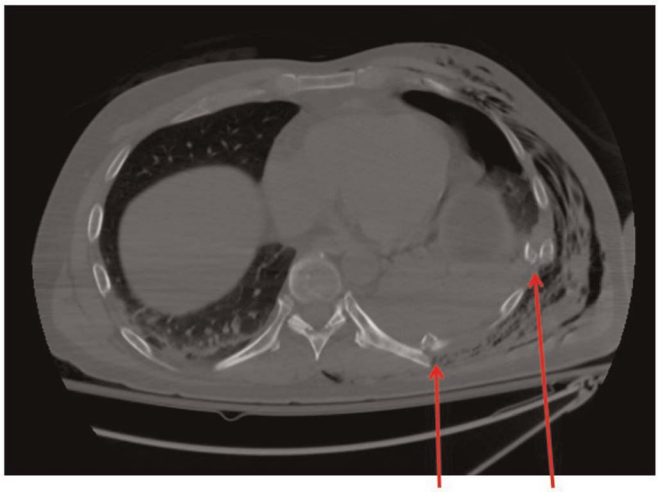

Figure 2. Two-dimensional axial view of the chest showing two 100% displaced rib fractures (arrows), hemothorax, and pneumothorax.

plate using locking screws.[43] A fifth system uses a molding titanium plate to hold the fracture in reduction without the need for locking screws. There are no head-to-head studies to determine the superiority of one technique over another for any particular fracture pattern or in any particular patient population.

The operative technique for all but one system involves using an anterior, muscle-sparing technique to isolate and reduce the fracture segment.[44] The plate is then placed across the fracture line to maintain the reduction and allow for bone healing. The sole exception is a plating system that involves thoracoscopically placing the plate against the undersurface of the rib, within the chest cavity.[45] As the plate is secured in place, the fracture reduces into anatomic position and is secured. There is currently no role for the use of absorbable plates or screws.[46]

Patient positioning, incision location, and the need for muscle division all depend on the location of the fracture series.

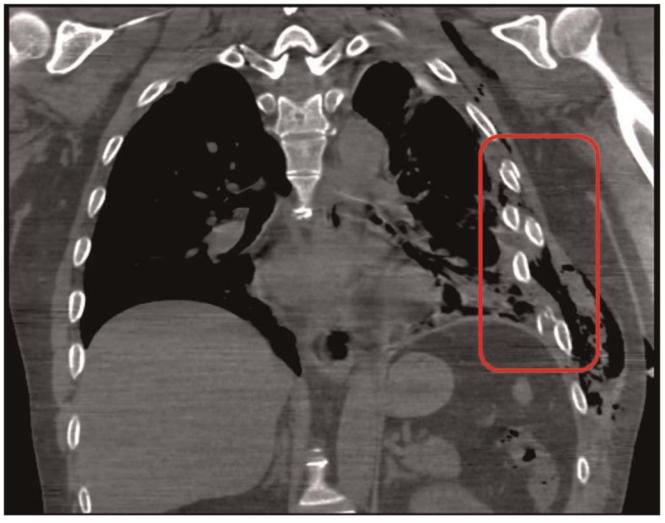

Figure 3. Two-dimensional coronal view of the chest showing multiple displaced rib fractures and subcutaneous emphysema (boxed area).

Figure 4. Three-dimensional view of the chest showing multiple 100% displaced and shortened rib fractures.

In most instances, the patient will be positioned in a lateral decubitus position.[44] This position provides access to the axillary line, which is the most common site of rib fractures, as well as the back. If the fracture(s) are solely posterior, prone positioning is another option. The exact location of the surgical incision can be based on measuring the distance from the sternum or spinous process of the vertebra to the fracture site as seen on a 2D CT scan, but one has to account for the curvature of the chest wall. Ultrasound can also be used to localize the fracture(s) prior to skin incision. If the fractures span a number of ribs, a vertical incision using muscle-sparing techniques to exposure the fracture line will avoid the need to raise large flaps and will mitigate the risk of postoperative seroma and need for drains. In a patient with flail chest where the fracture lines are far away from one another, two vertical incisions may be more effective than a long horizontal incision and need to raise flaps. The intrathoracic approach lessens the need to raise skin flaps as well.

© 2024 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2024 Wolters Kluwer Health, Inc. All rights reserved.

A unique aspect of ribs that the surgeon must be aware of when performing SSRF is that the ribs are most thin at the superior and inferior edges of the bone.[44] This necessitates that the plate and locking screws be placed in the middle of the rib. As well, the curvature and angulation of the chest wall differ along the length of the bone, and a long plate may need to be contoured to be properly apposed against the fracture(s). Next, the surgeon must take care to minimize dissection or stripping of the periosteum, as this is the blood supply to the bone. Excessive stripping of this layer can increase the risk of nonunion of the fracture.[44] Dissection along the inferior aspect of the rib should be avoided to minimize risk of injury to the neurovascular bundle.

Titanium is a malleable metal and thus prone to metal fatigue with excessive movement. The fracture segments must be reduced such that there is less than a 1-cm gap across the fracture line. A larger defect will result in plate fracture due to chest wall movement with breathing.[47,48]

COST EFFECTIVENESS OF SSRF

Despite the aforementioned benefits, there are significant costs associated with SSRF. The implants are expensive as is time in the operating room. These fixed costs must be less than the cost savings associated with SSRF to make the operation financially feasible and thus scalable beyond major trauma centers. A recent study using a Markov model found that SSRF was cost effective only in patients with flail chest using a willingness-to-pay threshold of $150,000 per quality-adjusted life year (QALY) gained.[49] This was true to both young and elderly patients. However, the model did not find cost benefit at this QALY threshold for any age group without flail chest. The operation was least cost-effective in patients 65 years and older without flail chest (243,758 per QALY). Another study, which was based on published reports and a decision-support model, similarly found that cost-effectiveness was most in patients with flail chest, especially if the patient was intubated prior to operation.[21]

ADDITIONAL CONSIDERATIONS

Several aspects of the care of patients with severe chest wall injuries are beyond the scope of this review but warrant mention to direct the reader to further exploration. Physical therapy, including kineotaping, is likely an integral component of recovery from both severe chest wall injury and SSRF but requires further investigation. Fixation of sternal and costo-cartilage fractures have been described but likely involves unique indications and techniques beyond the scope of this review. Next, recent data have suggested socioeconomic disparities in access to SSRF, as well as disparities in who agrees to the operation, and the time after injury at which surgery is offered.[50] Additional research is needed to elucidate the mechanisms surrounding these disparities and mitigate them. Lastly, a recent study using the National Inpatient Sample database suggested mortality and morbidity benefit for patients with severe chest wall trauma who were transferred to what the authors called "high-acuity trauma hospitals."[51] These were defined as hospitals that had a 0% incidence of the need to transfer neurotrauma patients elsewhere. Although the underlying reason for the findings is not known, the previously noted factors regarding multimodal pain control, ready availability of operating room to allow for timely SSRF, expertise to perform the operation quickly, and physiatry resources to allow for proper convalesces are likely common factors in these hospitals as compared with the control group.

CONCLUSION

Surgical stabilization of rib fractures is associated with decreased need for mechanical ventilation, pneumonia, length of stay, and, possibly, mortality in patients with respiratory failure due to flail chest. Because of this, it is cost-effective in this cohort regardless of patient age or the presence of brain injury. The role of SSRF in patients without ventilator dependent flail chest injury and in patients without flail chest remains more controversial. There may be a role for SSRF in these cohorts if their pain cannot be managed medically, but further studies are needed to more accurately identify those who are most likely to benefit from operation.

AUTHORSHIP

B.S. and F.P. contributed in the literature search, interpretation of data, drafting manuscript, and critical revision.

DISCLOSURE

Conflicts of Interest: Author Disclosure forms have been supplied and are provided as Supplemental Digital Content (http://links.lww.com/TA/D702).

REFERENCES

1. Ziegler DW, Agarwal NN. The morbidity and mortality of rib fractures. *J Trauma Acute Care Surg*. 1994;37(6):975–979.
2. Jones KM, Reed RL 2nd, Luchette FA. The ribs or not the ribs: which influences mortality? *Am J Surg*. 2011;202(5):598–604.
3. Sharma OP, Oswanski MF, Jolly S, Lauer SK, Dressel R, Stombaugh HA. Perils of rib fractures. *Am Surg*. 2008;74(4):310–314.
4. Bulger EM, Arneson MA, Mock CN, Jurkovich GJ. Rib fractures in the elderly. *J Trauma Acute Care Surg*. 2000;48(6):1040–1046 discussion 6-7.
5. Flagel BT, Luchette FA, Reed RL, Esposito TJ, Davis KA, Santaniello JM, et al. Half-a-dozen ribs: the breakpoint for mortality. *Surgery*. 2005;138(4):717–723 discussion 23-5.
6. Shackford SR, Virgilio RW, Peters RM. Early extubation versus prophylactic ventilation in the high risk patient: a comparison of postoperative management in the prevention of respiratory complications. *Anesth Analg*. 1981;60(2):76–80.
7. Pieracci FM, Schubl S, Gasparri M, Delaplain P, Kirsch J, Towe C, et al. The Chest Wall Injury Society recommendations for reporting studies of surgical stabilization of rib fractures. *Injury*. 2021;52(6):1241–1250.
8. Chen J, Jeremitsky E, Philp F, Fry W, Smith RS. A chest trauma scoring system to predict outcomes. *Surgery*. 2014;156(4):988–993.
9. Chapman BC, Herbert B, Rodil M, Salotto J, Stovall RT, Biffl W, et al. RibScore: a novel radiographic score based on fracture pattern that predicts pneumonia, respiratory failure, and tracheostomy. *J Trauma Acute Care Surg*. 2016;80(1):95–101.
10. Kyriakakis R, Johnson B, Krech L, Pounders S, Lypka M, Chapman A, et al. Planning for the worst: the impact of a comprehensive, risk associated treatment protocol on unanticipated ICU admissions in patients affected by rib fractures. *Am J Surg*. 2022;224(1 Pt B):602–606.
11. Burton SW, Riojas C, Gesin G, Smith CB, Bandy V, Sing R, et al. Multimodal analgesia reduces opioid requirements in trauma patients with rib fractures. *J Trauma Acute Care Surg*. 2022;92(3):588–596.
12. Moskowitz EE, Garabedian L, Hardin K, Perkins-Pride E, Asfaw M, Preslaski C, et al. A double-blind, randomized controlled trial of gabapentin vs. placebo for acute pain management in critically ill patients with rib fractures. *Injury*. 2018;49(9):1693–1698.
13. Carver TW, Kugler NW, Juul J, Peppard WJ, Drescher KM, Somberg LB, et al. Ketamine infusion for pain control in adult patients with multiple rib fractures: results of a randomized control trial. *J Trauma Acute Care Surg*. 2019;86(2):181–188.

© 2024 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2024 Wolters Kluwer Health, Inc. All rights reserved.

14. Kugler NW, Carver TW, Juul J, Peppard WJ, Boyle K, Drescher KM, et al. Ketamine infusion for pain control in elderly patients with multiple rib fractures: results of a randomized controlled trial. *J Trauma Acute Care Surg*. 2019;87(5):1181–1188.
15. King S, Smith L, Harper C, Beam Z, Heidel E, Carico G, et al. Intravenous lidocaine for rib fractures: effect on pain control and outcome. *Am Surg*. 2022;88(4):734–739.
16. Malekpour M, Hashmi A, Dove J, Torres D, Wild J. Analgesic choice in management of rib fractures: paravertebral block or epidural analgesia? *Anesth Analg*. 2017;124(6):1906–1911.
17. Adhikary SD, Liu WM, Fuller E, Cruz-Eng H, Chin KJ. The effect of erector spinae plane block on respiratory and analgesic outcomes in multiple rib fractures: a retrospective cohort study. *Anaesthesia*. 2019;74(5):585–593.
18. Elawamy A, Morsy MR, Ahmed MAY. Comparison of thoracic erector spinae plane block with thoracic paravertebral block for pain management in patients with unilateral multiple fractured ribs. *Pain Physician*. 2022; 25(6):483–490.
19. Slobogean GP, Kim H, Russell JP, Stockton DJ, Hsieh AH, O'Toole RV. Rib fracture fixation restores inspiratory volume and peak flow in a full thorax human cadaveric breathing model. *Arch Trauma Res*. 2015;4(4):e28018.
20. Shiroff AM, Wolf S, Wu A, Vanderkarr M, Anandan M, Ruppenkamp JW, et al. Outcomes of surgical versus nonsurgical treatment for multiple rib fractures: a US hospital matched cohort database analysis. *J Trauma Acute Care Surg*. 2023;94(4):538–545.
21. Swart E, Laratta J, Slobogean G, Mehta S. Operative treatment of rib fractures in flail chest injuries: a meta-analysis and cost-effectiveness analysis. *J Orthop Trauma*. 2017;31(2):64–70.
22. Doben AR, Eriksson EA, Denlinger CE, Leon SM, Couillard DJ, Fakhry SM, et al. Surgical rib fixation for flail chest deformity improves liberation from mechanical ventilation. *J Crit Care*. 2014;29(1):139–143.
23. Slobogean GP, MacPherson CA, Sun T, Pelletier ME, Hameed SM. Surgical fixation vs nonoperative management of flail chest: a meta-analysis. *J Am Coll Surg*. 2013;216(2):302–11.e1.
24. Pieracci FM, Lin Y, Rodil M, Synder M, Herbert B, Tran DK, et al. A prospective, controlled clinical evaluation of surgical stabilization of severe rib fractures. *J Trauma Acute Care Surg*. 2016;80(2):187–194.
25. Craxford S, Owyang D, Marson B, Rowlins K, Coughlin T, Forward D, et al. Surgical management of rib fractures after blunt trauma: a systematic review and meta-analysis of randomised controlled trials. *Ann R Coll Surg Engl*. 2022;104(4):249–256.
26. Dehghan N, Nauth A, Schemitsch E, Vicente M, Jenkinson R, Kreder H, et al. Operative vs nonoperative treatment of acute unstable chest wall injuries: a randomized clinical trial. *JAMA Surg*. 2022;157(11):983–990.
27. Leinicke JA, Elmore L, Freeman BD, Colditz GA. Operative management of rib fractures in the setting of flail chest: a systematic review and meta-analysis. *Ann Surg*. 2013;258(6):914–921.
28. Voggenreiter G, Neudeck F, Aufmkolk M, Obertacke U, Schmit-Neuerburg KP. Operative chest wall stabilization in flail chest—outcomes of patients with or without pulmonary contusion. *J Am Coll Surg*. 1998;187(2): 130–138.
29. Van Wijck SFM, Pieracci FM, Smith EF, Madden K, Moore EE, Wijffels MME, et al. Rib fixation in patients with severe rib fractures and pulmonary contusions: is it safe? *J Trauma Acute Care Surg*. 2022;93(6):721–726.
30. Pieracci FM, Agarwal S, Doben A, Shiroff A, Lottenberg L, Whitbeck SA, et al. Indications for surgical stabilization of rib fractures in patients without flail chest: surveyed opinions of members of the Chest Wall Injury Society. *Int Orthop*. 2018;42(2):401–408.
31. Pieracci FM, Leasia K, Bauman Z, Eriksson EA, Lottenberg L, Majercik S, et al. A multicenter, prospective, controlled clinical trial of surgical stabilization of rib fractures in patients with severe, NONFLAIL fracture patterns (Chest Wall Injury Society NONFLAIL). *J Trauma Acute Care Surg*. 2020;88(2):249–257.
32. Majercik S, Vijayakumar S, Olsen G, Wilson E, Gardner S, Granger SR, et al. Surgical stabilization of severe rib fractures decreases incidence of retained hemothorax and empyema. *Am J Surg*. 2015;210(6):1112–1116 discussion 6-7.
33. Pieracci FM, Leasia K, Hernandez MC, Kim B, Cantrell E, Bauman Z, et al. Surgical stabilization of rib fractures in octogenarians and beyond—what are the outcomes? *J Trauma Acute Care Surg*. 2021;90(6):1014–1021.
34. Prins JTH, Van Lieshout EMM, Ali-Osman F, Bauman ZM, Caragounis EC, Choi J, et al. Outcome after surgical stabilization of rib fractures versus nonoperative treatment in patients with multiple rib fractures and moderate to severe traumatic brain injury (CWIS-TBI). *J Trauma Acute Care Surg*. 2021; 90(3):492–500.
35. Lagazzi E, de Roulet A, Proano-Zamudio JA, Argandykov D, Romijn AS, Abiad M, et al. Is severe traumatic brain injury no longer a contraindication for surgical stabilization of rib fractures in patients with multiple rib fractures? A propensity-matched analysis. *J Trauma Acute Care Surg*. 2023; 94(6):823–830.
36. Lagazzi E, Rafaqat W, Argandykov D, de Roulet A, Abiad M, Proano-Zamudio JA, et al. Timing matters: early versus late rib fixation in patients with multiple rib fractures and pulmonary contusion. *Surgery*. 2024; 175(2):529–535.
37. Pieracci FM, Coleman J, Ali-Osman F, Mangram A, Majercik S, White TW, et al. A multicenter evaluation of the optimal timing of surgical stabilization of rib fractures. *J Trauma Acute Care Surg*. 2018;84(1):1–10.
38. Towe CW, Bachman KC, Ho VP, Pieracci F, Worrell SG, Moorman ML, et al. Early repair of rib fractures is associated with superior length of stay and total hospital cost: a propensity matched analysis of the national inpatient sample. *Medicina (Kaunas)*. 2024;60(1):153.
39. Lagazzi E, Argandykov D, de Roulet A, Proano-Zamudio JA, Romijn AC, Abiad M, et al. Evaluating the impact of timing to rib fixation in patients with traumatic brain injury: a nationwide analysis. *J Trauma Acute Care Surg*. 2023;95(6):846–854.
40. Leasia K, Prins JTH, Lawless R, Burlew CC, Moore EE, Platnick B, et al. Door to door in 24: factors that allow surgical stabilization of rib fractures within 24 hours of admission. *J Thorac Dis*. 2023;15(11):5922–5930.
41. Livingston DH, Shogan B, John P, Lavery RF. CT diagnosis of rib fractures and the prediction of acute respiratory failure. *J Trauma Acute Care Surg*. 2008;64(4):905–911.
42. Pulley BR, Taylor BC, Fowler TT, Dominguez N, Trinh TQ. Utility of three-dimensional computed tomography for the surgical management of rib fractures. *J Trauma Acute Care Surg*. 2015;78(3):530–534.
43. Prins JTH, Van Wijck SFM, Leeflang SA, Kleinrensink GJ, Lottenberg L, de la Santa Barajas PM, et al. Biomechanical characteristics of rib fracture fixation systems. *Clin Biomech*. 2023;102:105870.
44. Sarani B, Schulte L, Diaz JJ. Pitfalls associated with open reduction and internal fixation of fractured ribs. *Injury*. 2015;46(12):2335–2340.
45. Mischler D, Schopper C, Gasparri M, Schulz-Drost S, Brace M, Gueorguiev B. Is intrathoracic rib plate fixation advantageous over extrathoracic plating? A biomechanical cadaveric study. *J Trauma Acute Care Surg*. 2022;92(3): 574–580.
46. Marasco SF, Sutalo ID, Bui AV. Mode of failure of rib fixation with absorbable plates: a clinical and numerical modeling study. *J Trauma Acute Care Surg*. 2010;68(5):1225–1233.
47. Sarani B, Allen R, Pieracci FM, Doben AR, Eriksson E, Bauman ZM, et al. Characteristics of hardware failure in patients undergoing surgical stabilization of rib fractures: a Chest Wall Injury Society multicenter study. *J Trauma Acute Care Surg*. 2019;87(6):1277–1281.
48. Choi J, Marafino BJ, Vendrow EB, Tennakoon L, Baiocchi M, Spain DA, et al. Rib fracture frailty index: a risk stratification tool for geriatric patients with multiple rib fractures. *J Trauma Acute Care Surg*. 2021;91(6):932–939.
49. Choi J, Mulaney B, Laohavinij W, Trimble R, Tennakoon L, Spain DA, et al. Nationwide cost-effectiveness analysis of surgical stabilization of rib fractures by flail chest status and age groups. *J Trauma Acute Care Surg*. 2021;90(3):451–458.
50. Rebollo Salazar D, Velez-Rosborough A, DiMaggio C, Krowsoski L, Klein M, Berry C, et al. Race and insurance status are associated with different management strategies after thoracic trauma. *J Surg Res*. 2021;261:18–25.
51. Ferre AC, Towe CW, Bachman KC, Ho VP. Should rib fracture patients be treated at high acuity trauma hospitals? *J Surg Res*. 2021;266:328–335.

© 2024 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2024 Wolters Kluwer Health, Inc. All rights reserved.